

## DESCRIPTION

## ELECTROPHORETIC DISPLAY DEVICE

## 5 [TECHNICAL FIELD]

The present invention relates to an electrophoretic display device.

## [BACKGROUND ART]

10 By remarkable development of an information technology, an amount of varieties of information in society is increasing significantly.

In connection with this, needs of a display which is one of information output apparatus are  
15 increasingly stronger, so that studies on the display with respect to further improvements in definition, power consumption, weight, and thickness have been conducted actively.

In recent years, of these displays which have  
20 been researched and developed, electronic paper, which has a display quality equivalent to printed matter and permits electrical writing and flexible portability, has attracted attention. Further, the electronic paper is expected very much also as a means for solving a  
25 forest environmental problem which is in currently problematic due to mass consumption of paper. As one of candidates of the electronic paper, an

electrophoretic display apparatus has been proposed by Evans et al. in U.S. Patent No. 3,612,758.

The electrophoretic display apparatus includes an electrophoretic display device constituted by a pair of substrates disposed with a spacing therebetween, an insulating liquid filled in the spacing, colored electrophoretic particles (charged migration particles) dispersed in the insulating liquid, and a display electrode disposed along each of the substrates.

The colored electrophoretic particles are electrically charged positively or negatively, so that they are deposited on either one of the display electrodes depending on a polarity of a voltage applied to the display electrode. For example, the colored electrophoretic particles are deposited on the upper (display) electrode to provide a visible state of the colored electrophoretic particles or on the lower (display) electrode to provide a visible state of the insulating liquid. Thus, display is effected by utilizing a difference in color between the color of the electrophoretic particles and the color of the insulating liquid which has been dyed.

However, in such a conventional electrophoretic display device, when writing only depending on a gradation value (level) on the basis of image data is performed, a desired gradation value

display cannot be effected in some cases. This may be attributable to an influence of a DC component remaining in the electrophoretic display device.

Hereinbelow, the influence of the residual DC  
5 component will be described.

Figure 9 shows an embodiment of a structure of a conventional electrophoretic display device.

The electrophoretic display device includes: a dispersion liquid comprising positively charged black  
10 electrophoretic particles 11, negatively charged white electrophoretic particles 12, and an insulating liquid in which the black and white electrophoretic particles 11 and 12 are contained; Electrodes, comprising a first electrode 15 and a second electrode 16, for  
15 forming an electric field in the dispersion liquid by applying a voltage between the electrodes; an insulating layer 17 for separating the dispersion liquid 10 and the first electrode 15; an insulating layer 18 for separating the dispersion liquid 10 and  
20 the second electrode 16; and a partition wall for partitioning adjacent pixels.

In the electrophoretic display device of this type, a relaxation time constant of accumulated electric charges by drive of respective parts is  
25 different depending on physical properties of respective constitutional members. In the following description, the relaxation time constant is defined

as a product of an electric resistance and an electrostatic capacity (capacitance) of each part when an equivalent electric circuit is considered on the basis of an electric field generated by each part. For example, the relaxation time constant of the dispersion liquid 10 is a product of a resistance and a capacitance of the dispersion liquid 10, thus being in agreement with a product of a volume resistivity and a dielectric constant of the dispersion liquid 10.

When charges, such as ions contained in the dispersion liquid 10, accumulate at the insulating layer surface, a time constant at the time of discharging through the dispersion liquid 10 is determined by the above defined relaxation time constant.

When a time constant  $\tau_1$  of a dispersion liquid portion and a time constant  $\tau_2$  of an insulating layer portion satisfy  $\tau_1 \ll \tau_2$ , ions are accumulated (deposited) on either one of the upper and lower insulating layer surfaces depending on a polarity thereof in the case of continuously applying a voltage of one polarity, so that the charges are not readily attenuated due to the larger  $\tau_2$ . As a result, the charges are also left even at both ends, of the insulating layer portion, at which the charges are generally less liable to remain.

In this case, thereafter, even when the voltage applied between the electrodes is made 0 V,

the insulating layer portion also has a longer charge relaxation time, thus leaving the charges thereat for a long time. As a result, in spite of the fact that the voltage of 0 V is applied between the electrodes, an internal voltage due to the residual charges is generated upper and lower ends of the dispersion liquid portion. This internal voltage is a residual DC voltage. By the residual DC voltage, a voltage different from the applied voltage is applied between the upper and lower ends of the dispersion liquid portion to cause display image burning (burn-in).

Further, by such a phenomenon, in the case of performing a writing operation by reference to only information on an image to be displayed, a desired voltage cannot be applied to the electrophoretic particles 11 and 12. As a result, a desired display state cannot be obtained. More specifically, in drive of the electrophoretic display device by applying one-polarity voltage, i.e., a positive voltage or a negative voltage, a DC component remains in the electrophoretic display device, so that there arises such a problem that a voltage applied at the time of writing and an effective voltage applied to the electrophoretic particles 11 and 12 are different from each other.

Further, in such a case where the electrophoretic display device is driven to provide a

low optical response speed and cause visual recognition of reset display by a user, a base color of the electronic paper is white, so that the electrophoretic display device is strongly required to permit writing from white display reset. However, in the case where the writing from white display reset is performed in a conventional horizontal movement-type electrophoretic display device, a gradation optical level is changed with respect to a minute fluctuation in drive voltage, so that the electrophoretic display device is accompanied with such a problem that gradation control is difficult.

Hereinbelow, the cause of this will be explained. For example, in a conventional horizontal movement-type electrophoretic display device shown in Figure 10, at the time of white display reset, black electrophoretic particles 11 are deposited in a plurality of layers on a partition wall 7A provided with a first electrode 4A. An interparticular attraction force determined by values of surface energy of the electrophoretic particles 11 and the dispersion liquid 10 is weaker than an attraction force, exerted between the electrophoretic particles 11 and the partition wall 7A, determined by values of surface energy of the electrophoretic particles 11, the dispersion liquid 10, and the partition wall 7A.

Accordingly, the state in which the

electrophoretic particles 11 are deposited in the plurality of layers is unstable, so that the deposition state is changed by a slight change in electric field strength (intensity). As a result, an optical response characteristic in writing from white display reset is changed abruptly. In other words, the particles deposited state is changed even by the slight change in electric field strength to unstabilize a resultant optical response characteristic.

#### [DISCLOSURE OF THE INVENTION]

A principal object of the present invention is to provide an electrophoretic display device having solved the above described problems.

A specific object of the present invention is to provide an electrophoretic display device capable of alleviating accumulation of residual DC component and stabilizing an optical gradation level in writing from white display reset.

According to an aspect of the present invention, there is provided on an electrophoretic display device, comprising:

a first substrate and a second substrate which are disposed with a spacing therebetween,  
a partition wall disposed in the spacing,  
electrophoretic particles sealed in a closed

space, defined by the first and second substrates and the partition wall, in which a distribution state of the electrophoretic particles is changed to effect display,

5           a first electrode disposed at a side surface of the closed space, and

          a second electrode disposed at a bottom surface of the closed space,

          wherein the first electrode has an area  
10       substantially equal to or larger than an area of the second electrode.

          In the electrophoretic display device of the present invention, the first electrode disposed at a side surface of the closed space and the second  
15       electrode disposed at a bottom surface of the closed space have the substantially same area, whereby it becomes possible to perform such a drive that an opposite polarity voltage is alternately applied between the respective electrodes even in the case of  
20       repetitively performing display rewriting, thus alleviating remarkably the accumulation of the residual DC component. Further, by providing the first electrode with a larger area than that of the second electrode, it is possible to stabilize an optical  
25       gradation level in writing from white display reset.

          These and other objects, features and advantages of the present invention will become more



apparent upon a consideration of the following description of the preferred embodiments of the present invention taken in conjunction with the accompanying drawings.

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[BRIEF DESCRIPTION OF THE DRAWINGS]

Figure 1 is a perspective view showing a pixel structure of an electrophoretic display device according to First Embodiment of the present invention.

10        Figures 2(a) and 2(b) are sectional views each showing electric line of force at each pixel of the electrophoretic display device.

      Figures 3(a) and 3(b) are graphs each showing an electrooptical characteristic of the  
15        electrophoretic display device.

Figure 4 is a time chart for illustrating a drive sequence for effecting bipolar reset.

Figure 5 is a sectional view showing a pixel of an electrophoretic display device according to  
20        Second Embodiment of the present invention.

Figure 6 is a perspective view showing a pixel of an electrophoretic display device according to Third Embodiment of the present invention.

Figure 7 is a top view of the pixel of the  
25        electrophoretic display device shown in Figure 6.

Figures 8(a) and 8(b) are perspective view each showing pixel(s) of an electrophoretic display

device according to Fourth Embodiment of the present invention.

Figure 9 is a sectional view showing an embodiment of a structure of a conventional electrophoretic display device.

Figure 10 is a sectional view showing a state at the time of white display reset in a conventional horizontal movement-type electrophoretic display device.

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[BEST MODE FOR CARRYING TO THE INVENTION]

Hereinbelow, embodiments of the electrophoretic display device according to the present invention will be described with reference to the drawings.

(First Embodiment)

Figure 1 is a schematic perspective view showing a pixel structure of an electrophoretic display device according to this embodiment.

Referring to Figure 1, the electrophoretic display device includes a pixel G, a first substrate 1, a second substrate 2 disposed opposite to the first substrate 1 with a spacing therebetween, a partition wall 7 for keeping the spacing between the first and second substrates 1 and 2 at a predetermined distance and partitioning the pixel and an adjacent pixel, a closed space defined by the first and second

substrates 1 and 2 and the partition wall 7, a liquid-phase forming electrophoretic dispersion liquid 3 in which a liquid-phase dispersion medium and charged electrophoretic particles (not shown) dispersed in the dispersion medium are sealed, a second electrode 5 formed on the second substrate 2, and a first electrode 4 formed at a surface of the partition wall 7.

The electrophoretic display device in the embodiment is a matrix panel having 600x1800 pixels. Each pixel G has a height A of 20  $\mu\text{m}$ , a width B of 40  $\mu\text{m}$ , and a length (depth) C of 120  $\mu\text{m}$ . The first electrode 4 is formed at surfaces of a pair of partition wall 7 portions constituting a pair of opposite side surfaces. In this embodiment, two opposite side surfaces of four side surfaces and a bottom surface of the pixel G is coated with the electrodes (the first and second electrodes 4 and 5).

As the second electrode 5, a 1.1 mm-thick glass substrate is used, and the second electrode 5 is disposed at the pixel G. Each of the respective electrodes 4 and 5 is surface-coated with an insulating layer 6. As the electrophoretic particles contained in the electrophoretic dispersion liquid 3 which is sealed in the closed space are black particles. As the dispersion medium contained in the dispersion liquid 3 isoparaffin is used and, as the

electrophoretic particles, particles of polystyrene-polymethyl methacrylate copolymer (resin) (particle size: 1 - 2  $\mu\text{m}$ ) containing carbon black are used. At each pixel G, a thin film transistor (TFT) is  
5 formed and connected with a voltage application circuit, thus constituting an electrophoretic display apparatus.

Incidentally, in the case where, as shown in Figure 1, the first and second electrodes 4 and 5 have  
10 the same depth dimension (length) C and the first electrode 4 is divided into two portions which are formed at opposite two surfaces of adjacent partition wall portions 7, an area of the first electrode 4 means a sum of areas of these (first electrode) two  
15 portions 4.

In this embodiment, the pixel G has a ratio of A (height):B (width) of 1:2, so that the first electrode 4 and the second electrode 5 have the same area.

20 In such a case where the area of the first electrode 4 is equal to the area of the second electrode 5, as shown in Figure 2(a), a distribution of electric field strength is substantially symmetrical with respect to the electrode surfaces of  
25 the first electrode 4 and the second electrode 5. In other words, at the respective electrode surfaces, the electric field strength varies depending on a position

and has a distribution but a manner of the distribution from a maximum to a minimum on the first electrode surface is substantially identical to that on the second electrode surface.

5           More specifically, the electric field strength on the first electrode 4 is stronger with a shorter distance from the first substrate 1 and is weaker with a longer distance from the first substrate 1. On the other hand, the electric field strength on the second  
10 electrode 5 is stronger at a portion closer to the partition wall 7 and is weakened at a pixel center portion. The electric field strength is determined by a distance from a bonding (contact) portion of the partition wall 7 and the first substrate 1.  
15 Accordingly, as apparent from the ratio A:B of 1:2, the distribution of electric field strength on the first electrode 4 is substantially identical to that on 1/2 of the entire second electrode 5.

          Actually, the first electrode 4 contacts the  
20 second substrate 2 but the half of the second electrode 5 is connected with the other half of the second electrode 5. For this reason, the distributions of electric field strength on the first and second electrodes 4 and 5 are not completely identical to  
25 each other. Ideally, these distributions are completely identical to each other in such a state that both of the first and second electrodes are

extended infinitely. However, by the neglect of a difference in state between the end portion of the first electrode and the center portion of the second electrode, it can be said that both of the electric  
5 field strength distributions are substantially identical to each other.

Figure 2(b) shows a distribution of electric field strength in the case where the area of the first electrode 4 and the area of the second electrode 5 are  
10 not equal to each other. In this case, on the first electrode 4, the electric field strength is created relatively uniformly but on the second electrode 5, the electric field strength becomes very small at the center portion of pixel. As a result, distributions of  
15 the electric field strengths on the first and second electrodes are not equal to each other.

As shown in Figure 2(a), the distribution of electric field strength to be exerted on the electrophoretic particles is symmetrical with respect  
20 to the electrode surfaces of the first and second electrodes, so that a resultant electrooptical characteristic showing a relationship between an optical characteristic (R) and an applied voltage (V) is as shown in Figure 3(a), thus being improved  
25 compared with an electrooptical characteristic in the case of asymmetrical electric field strength distribution (Figure 2(b)) shown in Figure 3(b).

Here, in the case of a conventional electrophoretic display device having the electrooptical characteristic shown in Figure 3(b), there is a considerable difference in optical response characteristic between writing from white display reset and writing from black display reset, so that it is difficult to perform bipolar reset which effects opposite-polarity resets alternately. However, in the case of the electrophoretic display device of the embodiment having the electrooptical characteristic as shown in Figure 3(a), the optical response characteristic in writing from white display reset is substantially identical to that in writing from black display reset, so that it is possible to perform reset operation by alternately changing a polarity between a positive side and a negative side at the same voltage amplitude and perform writing at voltages of both of the polarities.

Figure 4 is a time chart showing a drive sequence for effecting bipolar reset of the electrophoretic display device of this embodiment. In the case of effecting the bipolar reset, first, a voltage  $V_{rw}$  is applied so as to effect white display reset and then an arbitrary gradation is written. Next, a voltage  $V_{rb}$  is applied so as to effect black display reset and then an arbitrary gradation is written. The voltages  $V_{rw}$  and  $V_{rb}$  have the same amplitude but have

opposite polarities. By effecting opposite-polarity resets alternately, it is possible to perform such a drive that a residual DC is less liable to accumulate. As a result, it is possible to perform stable display rewriting which is less liable to cause burn-in.

As described above, by providing the first electrode 4 and the second electrode 5 with the same area, it becomes possible to equalize the electric field strength exerted on the electrophoretic particles in writing from white display reset to that in writing from black display reset. As a result, it is possible to perform bipolar-voltage drive using positive and negative voltages (of both polarities). Further, even in the case of repeating display rewriting, it becomes possible to perform such a drive that the respective electrodes are alternately supplied with voltages of opposite polarities, so that accumulation of the residual DC component can be remarkably alleviated compared with a conventional monopolar-voltage drive and it is possible to remedy the burn-in problem.

Incidentally, there is substantially no problem even when the areas of the first and second electrodes 4 and 5 are not strictly equal to each other but substantially equal to each other so long as an optical characteristic in writing from white display reset with a predetermined gradation accuracy



is identical to that in writing from black display reset with the predetermined gradation accuracy.

(Second Embodiment)

Figure 5 is a schematic sectional view of a pixel of an electrophoretic display device according to this embodiment, wherein the same reference numerals as in Figure 1 represent the same or corresponding portions.

In Figure 5, black electrophoretic particles 11 are contained in an electrophoretic dispersion liquid 3. In this embodiment, a pixel G has a height (A) of 60  $\mu\text{m}$ , a width (B) of 40  $\mu\text{m}$ , and a length or depth (C) of 60  $\mu\text{m}$  (Figure 1). In other words, in this embodiment, a length in a height direction of the pixel G is longer than a length in a width direction.

Here, in the conventional electrophoretic display device, as described with reference to Figure 10, the electrophoretic particles 11 are deposited in the plural layers on a cell deposition surface at the time of white display reset and the particle deposition state is charged by the slight change in electric field strength, thus resulting in a problem of unstable optical response characteristic.

On the other hand, in the electrophoretic display device of this embodiment, the electrophoretic particles 11 at the time of white display reset are deposited in a single layer on the cell deposition

surface as shown in Figure 5 because of the larger height (A) of the pixel G.

When the electrophoretic particles are preset at the electrode surface in such a state that they are deposited in the plurality of layers, electrophoretic particles directly contacting the electrode have a strong deposition force but electrophoretic particles located at an upper portion of the plurality of layers thereof have a weak deposition force, thus being suspended in the dispersion liquid by a slight oscillation or shaking. In the conventional electrophoretic display device, one of the causes of an unstable collected state of electrophoretic particles on the partition wall compared with an extended state of electrophoretic particles on the substrate may be attributable to the deposition state of electrophoretic particles in the plural layers.

On the other hand, in such a deposition state of electrophoretic particles that the electrophoretic particles are deposited on the second electrode in the single layer, i.e., without being overlies, the particle deposition state is stable and is less liable to be changed by the slight change in electric field strength, so that the optical characteristic of the electrophoretic display device is not largely changed by a slight change in applied voltage. Accordingly, compared with the conventional electrophoretic display

device, the electrophoretic display device of this embodiment can stabilize an optical gradation level in writing from white display reset and improve a controllability in gradation writing from the white display reset.

As described above, by providing the first electrode 4 with an area which is larger than an area of the second electrode 5, the electrophoretic particles 11 are placed in such a deposition state that they are deposited in the single layer in white display reset. As a result, it is possible to improve a gradation controllability in writing from the white display reset.

Incidentally, when the first electrode 4 is provided with an excessively large area, a height of the partition wall 7 for partitioning adjacent pixels is also increased. As a result, a production process becomes difficult and there arise problems of lowering in light reflectance, viewing angle, etc. For these reasons, the area of the first electrode 4 may preferably be not more than approximately three times the area of the second electrode 5.

(Third Embodiment)

Figure 6 is a schematic perspective view of a pixel of an electrophoretic display device according to this embodiment, wherein the same reference numerals as in Figure 5 represent the same or

corresponding portions.

In Figure 6, a pixel G has a height (A) of 10  $\mu\text{m}$ , a width (B) of 40  $\mu\text{m}$ , and a length or depth (C) of 40  $\mu\text{m}$ , and four side surfaces and a bottom surface of the pixel G are coated with electrodes. More specifically, in this embodiment, at four side surfaces (including two pairs of opposite surfaces), the first electrode 4 is disposed.

Here, in such a electrophoretic display device, as described above, even when the first and second electrodes 4 and 5 are provided with the same area, electric field strengths at points on the first and second electrodes 4 and 5 which have the same distance from a contact line (edge) between the first and second electrodes 4 and 5 are not accurately equal to each other. For this reason, in this embodiment, by adjusting a thickness of the insulating layer 6, the electric field strengths at the points on the first and second electrodes 4 and 5 which have the same distance from the contact line are made equal to each other.

For example, as shown in Figure 7 which is a top view of the pixel G, the thickness of the insulating layer 6 of the second electrode 5 is made larger at four corners of the pixel G where the electric field strength is stronger and made smaller at a pixel center portion where the electric field

strength is weaker, whereby it becomes possible to perform bipolar drive at the same drive voltage.

Further, a distance from the first electrode 4 to the surface of the insulating layer 6 thereon and a distance from the surface of the insulating layer 6 thereon are made equal to each other, and when an intersection line is taken as a line of intersection of an extended plane of the first electrode surface and an extended plane of the second electrode surface, a distance from the intersection line to an edge of the first electrode surface closest to the intersection line and a distance from the intersection line to an edge of the second electrode surface closest to the intersection line are made equal to each other. As a result, it is also possible to make the electric field strengths at the points on the first and second electrodes having the same distance from the edge line between the first and second electrodes, equal to each other.

By adjusting so, the electric field strength exerted on the electrophoretic particles is symmetrical with respect to the white display reset and the black display reset. As a result, the optical response characteristic is improved compared with the conventional one, thus resulting in the above described electrooptical characteristic as shown in Figure 3(a). More specifically, the optical response

characteristics in writing from the white display reset and from the black display reset are substantially identical to each other, thus permitting the bipolar reset operation.

5           By effecting the above described sequence shown in Figure 4, the opposite-polarity reset can be performed alternately to realize such a drive that the residual DC component is less liable to accumulate. As a result, it is possible to effect stable display  
10   rewriting with less occurrence of the burn-in.

          Incidentally, in the case where the distance from the first electrode 4 to the insulating layer 6 surface thereon (first distance) and the distance from the second electrode 5 to the insulating layer 6  
15   surface thereon (second distance) cannot be made equal, when these first and second distances satisfy the relationship of: (first distance) > (second distance), it becomes possible to effect the bipolar drive at the same drive voltage (amplitude) by satisfying the  
20   relationship: (electrode area of first electrode 4) < (electrode area of second electrode 5).

          On the other hand, when the first and second distances satisfy the relationship of: (first distance) < (second distance), it becomes possible to  
25   effect the bipolar drive at the same drive voltage (amplitude) by satisfying the following relationship: (electrode area of first electrode 4) > (electrode

area of second electrode 5).

(Fourth Embodiment)

Each of Figures 8(a) and 8(b) is a schematic perspective view of a pixel of an electrophoretic display device according to this embodiment, wherein  
5 the same reference numerals as in Figure 1 represent the same or corresponding portions.

In Figures 8(a) and 8(b), a side surface electrode 8 for preventing an electric field generated  
10 by a first electrode 4 and a second electrode 5 from adversely affecting adjacent pixels is disposed at opposite two side surfaces of four side surfaces of a pixel G.

More specifically, in this embodiment, of the  
15 four side surfaces of the pixel G, the side surface electrode 8 is disposed at opposite two side surfaces and the first electrode 4 is disposed at other opposite two side surfaces. These four side surfaces and a bottom surface of the pixel G are coated with  
20 electrodes (the first and side surface electrodes 4 and 8 and the second electrode 5).

In this embodiment, the pixel G has a height (A) of 20  $\mu\text{m}$ , a width (B) of 40  $\mu\text{m}$ , and a length (depth) (C) of 60  $\mu\text{m}$  as shown in Figure 8(a), so that  
25 an areal ratio between the side surface electrode 8 and the first electrode 4 is 2:3.

When three pixels G, each having the size

shown in Figure 8(a), capable of displaying red, green and blue are arranged as shown in Figure 8(b), the influence of the side surface electrodes 8 can be reduced. As a result, it becomes possible to perform  
5 drive of the electrophoretic display device only by the first electrode 4.

Incidentally, by making the length (depth) (C) of the pixel G longer, i.e., making the B:C ratio being not less than 1:3, an electrode area of the  
10 first electrode 4 is not less than three times that of the side surface electrode 8. As a result, the first electrode 4 is dominant with respect to determination of a distribution of electric field in the pixel G, so that the influence of the side surface electrode 8 in  
15 drive of the electrophoretic display device is further reduced.

In the above describe embodiments, the first electrode 4 has a substantially rectangular shape but may be a substantially triangular shape or a  
20 substantially polygonal shape.

#### [INDUSTRIAL APPLICABILITY]

As described hereinabove, according to the present invention, it is possible to provide a  
25 practical electrophoretic display device wherein the first electrode disposed at a side surface of the closed space and the second electrode disposed at a



bottom surface of the closed space have the substantially same area, whereby it becomes possible to perform such a drive that an opposite polarity voltage is alternately applied between the respective  
5 electrodes even in the case of repetitively performing display rewriting, thus alleviating remarkably the accumulation of the residual DC component. Further, by providing the first electrode with a larger area than that of the second electrode, it is possible to  
10 stabilize an optical gradation level in writing from white display reset in the electrophoretic display device.

While the invention has been described with reference to the structures disclosed herein, it is  
15 not confined to the details set forth and this application is intended to cover such modifications or changes as may come within the purpose of the improvements or the scope of the following claims.